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Marvin L. Hayenga
Iowa State University

BIOTECHNOLOGY: IMPLICATIONS FOR AGRIBUSINESS IN THE 1990s

by Marvin L. Hayenga

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*Professor of Economics, Iowa State University, and Visiting Professor, Department of Agricultural Economics, University of California, Davis, September 1987-March 1988.

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Products from biotechnology research are beginning to emerge into the commercial market. However, there has been a long gestation period which followed the investor fervor associated with the promise of new products from biotechnology and the spawning of many small biotech research firms to capitalize on these new technologies. Biotechnology in practice is typically considered to include not only genetic engineering, involving recombinant DNA procedures, but some of the older and closely related tools of cell culture, plant regeneration, monoclonal antibodies, embryo transfer, and bioprocess engineering (Agricultural Biotechnology: Strategies for National Competitiveness, 1987). These are extensions of the age-old techniques of plant and animal breeding and selection that work with the entire organism; the effort is now with individual genes within the organism (Walbot, 1987).

In 1985, responding to congressional interests, the Office of Technology Assessment (OTA) studied emerging technologies (including biotechnology) using a Delphi approach with 300 scientists to identify the nature of technological change, its timing, and its impact on the structure of agriculture (OTA, 1986). The OTA study, two Food and Drug Administration (FDA) surveys on emerging veterinary products and food biotechnology (FDA, 1986, 1988), and the University of California survey of biotechnology companies in 1987-88 reported here suggest that the biotech products that have reached public attention, and the very few in the commercial market, are only the tip of an iceberg. A number of products will be reaching the market place in the next five years, and the volume will greatly expand in the late 1990s.

During October 1987 - February 1988, research or product development managers in 24 leading companies involved in agricultural biotechnology research or product development were interviewed in a personal visit or by telephone. Each survey respondent was asked to identify (1) the new biotechnology products likely to enter the market place for use in plant or animal agricultural production, or in the food processing industry in the next decade, (2) the approximate time when these new products will enter the market, and (3) the application in which the products will first be used. The responses, supplemented by recent biotechnology literature and interviews with academic biotechnologists, provide the basis for the biotechnology forecasts presented here. (For more detail, see Hayenga, 1988). The implications of the likely developments in biotechnology for the agribusiness sector are then explored.

BIOTECHNOLOGY INNOVATIONS ON THE HORIZON

Currently, there are relatively few products or processes utilizing recombinant DNA technology or less sophisticated biotechnology being marketed in the food and agricultural sector. Among the most noteworthy now being marketed are embryo transplants; microbial soil, silage and hay inoculants; numerous fermentation processes and products involving yeast or other cultures; biopesticides; the first recombinant animal vaccines; monoclonal antibodies for diagnostic uses; and a genetically engineered enzyme in corn syrup production.

During the next five years, a large number of products from biotechnology will enter the agriculture or food processing market. Most are now in or nearing the field-testing stage or being subjected to a regulatory clearance process, if required. The bulk of these products will come from cell culture and cloning, or from other procedures short of genetic engineering (to avoid the regulatory hurdles and costs imposed on genetic engineered products). But a number of products from genetic engineering are also likely to enter the market, especially transgenic plants and products derived from transgenic bacteria. In addition, some offshoots from human medical research on cancer, AIDS, and the human immunity system may be applied to agricultural problems. We will focus initially on a few product areas with relatively large economic importance where biotech innovations are likely to emerge on the market in the next few years.

GROWTH PROMOTANTS

Several major chemical and pharmaceutical companies have had growth promotants for dairy cattle and swine in the field-testing stage of development for several years. Bovine somatotropin (BST), or dairy growth hormone, has been a subject of controversy among dairymen, legislators, and consumer groups. BST was identified over 50 years ago, but production was not possible on a commercial scale until recently when the growth hormone gene was inserted into bacteria which could reproduce it in large quantities. Original estimates of a 30 to 40 percent increase in milk production per cow are now scaled down to a more realistic figure of 10 to 15 percent. Still, there are concerns about dislocation of small dairy farmers. There are also fears about negative consumer reaction to hormones in milk--though there should not be any health issues with this type of hormone. Current industry estimates of likely FDA approval are 1990 or 1991.

Potentially more important is the porcine somatotropin (PST). This new product could lead to some growth rate improvements in market hogs, and to major improvements in carcass fat content (-1/3), lean content (+1/7) and feed use per pound of gain (-1/4). The prospect of significantly improved product quality combined with lower production costs from these growth promotants (produced using transgenic bacteria) could begin to be realized by 1989 or 1990. The impact on the position of pork versus competing meats could be significant, resulting in major structural shifts in the livestock and meat sector. Two companies have plants for commercial production of PST built or under construction.

BIOLOGICAL CONTROL AGENTS

Biological control agents (e.g., bacteria, viruses, fungi) often can be used as alternatives to chemicals in agriculture. As the public concerns about the effects of agricultural chemicals increase or re-registration costs for "old" chemicals lead to their discontinuation, biotech and chemical companies expect that biological controls will be in greater demand. Targeted "pests" may be weeds, insects, nematodes, fungi, viruses, or bacterial infestations (i.e., competing biological systems) which adversely affect the productivity of agricultural crops.

Biological control may also be used against competing organisms not conventionally viewed as pests. The goal is to displace the organism with an adverse characteristic, such as the bacteria which promote ice crystal formation on plants.

The range of biological control agents is potentially quite broad, and is one of the primary focal points of agricultural product development in the biotech industry. Progress is being made in identifying a broader variety of possible control agents (e.g., more natural toxins for plant pests) and improving their potency, to make them competitive with some chemical alternatives, or at least good second-best substitutes if and when certain chemicals are no longer available.

Currently, biopesticides for insect control are likely candidates for new product introductions in the next few years. Products using the Bt toxin appear likely for forestry crops, targeting the gypsy moth and the spruce bud worm, and for some large commercial agricultural crops like potatoes (potato beetle) and corn (corn borer). In addition, plant fungal diseases, difficult to control with current technology, are the focus of several new biological control products likely to be introduced as early as 1988. Researchers have been screening soil bacteria to find those with significant anti-fungal activity. These can be reproduced and used in their natural form, though efficiency and environmental survivability may vary, or the genes contributing anti-fungal activity can be identified and used in genetically modifying soil bacteria. Products aimed at cotton seedling and vegetable seedling diseases are likely to be available in the next year or two. New products for fungal diseases in several vegetable crops, fruit crops, and wheat are expected in the early 1990s, and a corn fungal control product is likely within the next five years.

Other biological controls use microbial competitors designed to compete with harmful microbes or serve as pathogens for undesirables like weeds. During the next five years, the controversial ice-minus bacteria should become commercially available, possibly as early as 1991. Fruit and berry crops are likely early commercial applications, thereby escaping crop loss associated with freezing temperatures during the critical blossoming period. Strawberries, almonds, cherries, peaches, and pears are the first crops likely to have microbial sprays to provide less susceptibility to frost; grapes, coffee, and other frost-sensitive crops will have similar products by the mid 1990s.

TRANSGENIC CROPS

A major class of genetic engineering products likely to emerge in the next five years is the transgenic agricultural crop. The first such major biotechnology breakthrough used E. Coli bacteria to produce desired plasmids, and introduced them into a modified Agrobacterium soil bacteria to transfer agriculturally useful genes into plants. Many plants are receptive to this method of genetic transmission, including tomato, potato, petunia, tobacco, carrot, poplar, celery, alfalfa, lettuce, flax, oilseed rape, sugarbeet, and asparagus. However, cereals and other monocots are much less amenable to this method. In particular, the task of regenerating the cells and producing the plants is more difficult. This difference in ease of engineering and reproduction is a primary determinant of which crops will be in the first or second generations of genetic-engineered agricultural crops (Rogers, 1987).

Several major agricultural chemical or biotechnology companies are field testing plants genetically engineered for herbicide resistance and insect resistance, while more limited work involves viral resistance and fungal resistance. The crop focus initially has been on simpler plants whose genetic structures were among the first to be mapped. These are typically viewed as prototypes for more complex, but commercially important crops, yet unmapped. The primary investment in research and field testing of transgenic agricultural crops has been with tobacco, tomatoes, potatoes, and canola (rapeseed). These may begin to emerge on the market in 1992 or 1993. Meanwhile, crops like corn, wheat, soybeans, and cotton have been on the back burner. However, recent developments in genetic engineering technology, including microinjection for DNA entry through cell walls, and improvements in plant regeneration techniques make grasses, like corn and wheat, good candidates for progress in the mid to late 1990s.

Genes which give plants resistance to several major classes of herbicides have been identified. Several major chemical companies and biotech companies, or joint ventures between chemical and biotech companies, are actively involved in developing herbicide resistant crops. Tomatoes resistant to glyphosphates, sulfonylurea, or bromoxinil are undergoing field tests in 1988, as are rapeseed (canola) and tobacco for some of the same herbicides. Alfalfa, corn, and wheat are also candidates for relatively early application of transgenic herbicide resistance. In addition, tissue culture techniques have been used to develop strains of corn which are resistant to a major herbicide.[1] Recently, a genetic engineered herbicide tolerant soybean has been patented.

Insect resistance involving Bt gene transfers has been field-tested in tobacco and tomatoes already, so the market entry could be within four to six years. Other genetically engineered crops such as rapeseed, cotton, and potatoes, will follow. Natural toxins will also be exploited against other plant predators. These toxins typically have quite specific target insects, so the use of chemicals or biopesticides may still be necessary to control other insects not affected by that toxin. Thus there could be displacement of some, but not all chemical insecticides until broader spectrum coverage is achieved by multi-toxin gene transfers into commercial crop varieties.

Virus resistant plants have also been field tested in tomatoes. While viruses have not been considered a major problem in many commercial crops, significant yield increases for tomatoes were observed in Monsanto's 1987 field test of virus resistance (Rogers, 1987). Tomatoes and potatoes, where virus problems are important, are potential early market transgenic crops with virus resistance.

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[1]For an excellent discussion of genetically engineered crop resistance, see Giaquinta, 1986.

VALUE-ADDED CONSUMER AND PROCESSING PRODUCT CHARACTERISTICS

During the next five years, a relatively small number of products will emerge from the biotech research pipeline which will change the characteristics of the ultimate consumer food product, or the product being further processed. Most of these will be products of tissue culture or related techniques, rather than genetic engineering. In some cases, natural components of foods can be isolated and cloned into a producing organism, possibly a plant or, more likely, a bacteria or yeast. Then, fermentation processes can produce large quantities of these natural components. In other cases, plant cells with desired characteristics can be cultured to rapidly reproduce more biochemically complex flavors or other characteristics which reflect more fully the essence of the natural product.

In addition to food ingredients and new food products with improved consumer or processing characteristics, new industrial or pharmaceutical products may be forthcoming from the plant or microbial production process. The somatotropins for pork production are an excellent example of a fermentation product to be sold by animal health products companies, causing consumer pork products to be dramatically lower in fat content.

Drawing from our industry survey, the 1988 FDA survey, and an excellent status report on food biotechnology by an Institute of Food Technology expert panel (Food Technology, 1988), it appears that the most significant areas of progress in food processing are likely to be in enzyme technology and in fermentation products and processes, though some agronomic improvements in plant characteristics important for processing or to the consumer will reach the market.

VALUE-ADDED PLANT CHARACTERISTICS

Several biotech companies have been developing "higher solids" tomatoes, potatoes, and onions to reduce the tonnage processed per unit of output, and related energy and waste treatment expense. These products usually are based on standard genetic selection procedures, though genetic engineering is also being explored to achieve the same goals.

At least one company has test-marketed new strains of carrots, celery, and other vegetables which have more crispness, sweetness, or less stringiness, etc. In the research pipeline, there are a number of products like fluffier popcorn, perhaps with its own salty taste and better flavors, seedless peppers, pineapple with novel colors or flavors, and naturally low caffeine coffees developed using tissue culture methods. Bruise tolerance and ripening or softening characteristics are areas where progress is being made in some products, where initial market entries within five years are a possibility. A few companies are nearing commercial development of alfalfa with increased leaf storage protein (for livestock feed). Others are working on oilseeds (like rapeseed or sunflower) with a higher processing yield of oil or more desirable fatty acid composition (e.g., high oleic acid) for either improved nutritional properties (degree of saturation) or shelf-life enhancement (of the oil itself or the food products using it).

Genetic engineering is being used to introduce color genes from one flower to others. For example, genes conferring blue colors to petunias can be transferred to roses, carnations, or chrysanthemums to provide some unique ornamentals in the next few years. And genetic introduction of a human growth hormone into tobacco could result in an agricultural plant being used as a factory to produce pharmaceutical products.

Cell culture production techniques are being used to generate natural vanilla, grape, and strawberry flavors from cells of those plants, with other fruit or berry flavors also possibilities in the next few years. Product yields are often many times greater than found in the native plant, making this a potentially commercial source of high value natural products providing desirable flavors, colors, preservatives, or nutritional supplements (Food Technology, 1988).

Textural changes in food products utilizing bioengineering techniques provide the basis for some potential new products in the next few years. Hydrolyzing proteins or mechanical means of protein structure modification can bring about textural changes which can greatly change perceived food characteristics. For example, the recently announced Simplesse low-calorie fat substitute (restructured milk and egg protein) could potentially reach the market in dairy products in the next few years.

FOOD-PROCESSING ADVANCES

Food processing advances coming from biotechnology are more likely to go unnoticed or be of little concern to the general public, since they will be developed at the processing level without obvious direct impact on consumers. During the next five years, advances in enzyme technology and related processing efficiency are reportedly the potentially most important biotechnology developments. Enzymes are important in the production of high-fructose corn syrups, brewing, baking, dairy processing, and meat tenderization. Recently Pfizer has developed a genetically engineered enzyme (rennet) which can be produced by fermentation rather than by extracting it from byproducts of beef packing, significantly improving its availability for cheese makers. Enzyme immobilization by attaching an enzyme to a stable supporting material is likely to significantly enhance enzyme viability in more efficient continuous production processes. Enzymes such as lipases for fats or proteases for proteins can be made to function in processing environments that previously were inhospitable; now these more complex fat or protein molecules can be broken into components, with different characteristics (e.g., to enhance or eliminate certain flavors). A new alcohol oxidase enzyme may facilitate oxygen absorption in food packages, increasing shelf life. Also enzymes are being developed to facilitate measurement of such product attributes as alcohol content, and facilitate quality control in food production and processing. Genetic engineering now offers the opportunity for more than one enzyme to be combined with other materials to reduce processing steps and time (e.g., a genetically engineered yeast strain with an enzyme added to simultaneously produce alcohol and reduce the carbohydrates in light beer production, thus speeding up the brewing process).

The fermentation process is the other area where some significant biotechnology innovations may emerge in the next five years. Some examples derived from an expert panel of food technologists are listed in Table 1.

Table 1. Dates of Technical Feasibility and Commercial Availability for Most Frequently Identified Targeted Biotechnology Areas

Area	No. of Citations[a]	Estimated Mean Range of Technical Feasibility	Estimated Mean Range for Commercial Availability
rDNA to Produce Vaccines	186	1987-88	1989-91
Growth Hormones[b]	134	1986-87	1989-91
Monoclonal Antibodies (MABs) to Diagnose Animal Disease or Conditions	106	1986-87	1987-88
Interferons/Interleukens	65	1987-88	1989-91
Other Probes/Vectors[c]	63	1986-87	1988-89
Genetic Modification (Somatic and Germ Line)	60	1988-89	1993-94
MABs to Control Large Scale Disease Problems	56	1988-89	1989-91
Augmentation of Feed Additives	42	1987-88	1989-91
Antibiotics, Drugs	37	1987-88	1989-91

[a]Includes both general citations of the target area, and citations of specific products within the target area.

[b]Includes the two most frequently identified products - Bovine Growth Hormone, Porcine Growth Hormone.

[c]Other Probes and Vectors include a variety of disease technologies, including rDNA probes to diagnose disease; regulation and enhancement of the immune system; and specialized assays such as ELISA (Enzyme-Linked Immuno Absorbant Assays).

Source: Emerging Developments in Veterinary Biotechnology, U.S. Food and Drug Administration, U.S. Department of Commerce, National Technical Information Service (PI86-222379), July 1986.

Molds, yeast, or bacterial fermentation processes now provide many of our food ingredients (e.g., vitamins, amino acids, enzymes, antioxidants), in addition to the consumer products that we more typically associate with fermentation--beer, sourdough bread, cheese and yogurt, etc. With increased microbial densities and yields from fermentation processes that are now feasible, many more products from fermentation will be potentially profitable commercial products, not just pharmaceutical products, cosmetics and colors that sell at extremely high values per pound (such as Japanese production of royal purple pigments via fermentation).

One of the primary near-term applications of biotechnology is in improving starter culture (bacteria) efficiency; the light beer technology mentioned above is one example, while cheese cultures are another prime area of new product development. Several strains of microbes in or near the regulatory clearance stage enhance flavor development in cheese production (a novel lipase enzyme has recently been introduced commercially), speed up the ripening process, or serve as inhibitors to viruses or other pathogens which can develop in the production process. Genetically engineering pathogenic resistance into the culture organisms could inhibit such problems as listeria or salmonella infections prone to develop in cultured consumer products.

Other fermentation processes (meat, vegetables, dairy) are being developed: stabilized lactose fermentations, purer starter cultures in meat fermentations to reduce staphylococcus infection outbreaks; and novel procedures to improve nutritive quality, product texture, or produce new flavor enhancers, sweeteners, natural flavors, or acidulants. For example, the peptide thaumatin which has extreme sweetness has been isolated from West African fruit. If some aftertaste problems can be solved, genetic engineering of that peptide into bacteria, and fermentation production processes could result in another low calorie natural sweetener.

OTHER NEAR-TERM PRODUCT INTRODUCTIONS

Micropropagation of cloned plant embryos is another new biotechnology technique likely to be emerging in the new future. By using tissue culture techniques to differentiate and clone improved plants, then encapsulating these embryos and using them instead of seed, genetic purity can be assured, disease exposure can be limited, and time involved to produce an adequate supply of seed can be sharply reduced. Companies are now applying these techniques to such diverse crops as potatoes, cashews, and date palm.

Finally, the recent developments in human immunity system boosters and anti-viral prophylactic products could extend to the animal veterinary market in a few years. (These and other development possibilities noted in the FDA 1985-1986 survey are listed in Table 2). Anti-virals like alpha interferon or similar anti-bacterials may have possibilities in mastitis or shipping fever control. Immunity system boosters, like interleukin-2 in combination with other products, could find new anti-bacterial uses in the livestock and poultry industries. Microinjection of anti-virals, anti-bacterials, or growth hormones into chick embryos (in the egg) is nearing commercialization in the poultry industry.

Table 2. Some Possibilities for Microbial Production of Actual and Potential Food Ingredients

Ingredient	Function	Producing Organisms
Acetic acid	Acidulant	Acetobacter pasteurianus
N-acetyl tripeptide	Immune enhancer	Bacillus cereus
D-arabitol	Sugar	Candida diddensii
Beta-carotene	Pigment	Blakeslea trispora
Chrysogenin	Pigment	Penicillium chrysogenum
Citric acid	Acidulant	Aspergillus niger
Citronellol	Fruity flavor	Ceratocystis spp.
Curulan	Thickener	Alcaligenes faecalis
Diacetyl	Buttery flavor	Leuconostoc cremoris, Streptococcus lactis
Dextrans	Thickeners	Leuconostoc mesenteroides
Emulsifier	Emulsification	Candida lipolytica
Fatty acid esters	Fruity fragrances	Pseudomonas spp.
Gamma-decalactone	Peach fragrance	Sporobolimyces odorus
Geraniol	Roselike fragrance	Kluyveromyces lactis
Glycerol	Humectant	Bacillus licheniformis
Glutamic acid	Flavor enhancer	Corynebacterium glutamicum
Lactic acid	Acidulant	Streptococci and lactobacilli
Leucine	Amino acid	Brevibacterium lactofermentum
Lysine	Amino acid	Corynebacterium glutamicum
Mannitol	Sugar	Torulopsis mannitofaciens
Methanol	Flavor	Pseudomonas putida
3-methoxy-3-isopropyl-pyrazine	Potato odor	Pseudomonas perolens
Methylbutanol	Malt flavor	Streptococcus lactis var maltigenes
3-methylbutylacetate	Banana fragrance	Ceratocystis moniliformis
Monascin	Pigment	Monascus purpureus
Nisin	Antimicrobial	Streptococcus lactis
5-nucleotides	Flavor enhancers	Corynebacterium glutamicum
6-pentyl-2-pyrone	Coconut fragrance	Trichoderma viride
L-phenylalanine	Aspartame precursor	Bacillus polymyxa
Proline	Amino acid	Serratia marcescens
Sesquiterpenes	Fruity fragrance	Lentinus lepideus
Surfactant	Wettability	Bacillus licheniformis
Tetramethylpyrazine	Nutty flavor	Bacillus subtilis, Corynebacterium glutamicum
Thermogelable polysaccharides	Thickeners	Argobacteriumm radiobacter
Vitamin B-12	Vitamin	Propionibacterium
Xanthan gum	Thickener	Xanthomonas campestris
Xylitol	Sweetner	Torulopsis candida

Source: Food Technology, January 1988.

LIKELY INNOVATIONS IN THE LATE 1990s

Commercial product introductions from biotechnology are likely to increase in number and importance five to ten years from now.

Growth stimulants for livestock and poultry (produced via recombinant DNA technology) will develop further as increased scientific knowledge of the hormonal checks and balances in commercial animals improves first generation products (especially the somatotropins), and bring on the next generation of growth regulators or stimulators. This second wave includes the growth hormone releasing factor, which causes the animal to produce more of its own growth hormone, somatomedins and insulin growth factors (possibly more direct growth stimulants), and somatostatin inhibitors (which release the brakes on growth hormone effectiveness). In addition to these growth promotants, the luteinizing hormone releasing factor may become available, fostering the growth and leanness benefits of male sex hormones (perhaps in beef cattle or swine) without their present disadvantages.

A few experts forecast that the introduction of growth hormone genes into farm animals may become a commercial reality toward the end of the next decade, replacing injection and implantation of growth stimulants. The initial targets of research are on the growth, feed efficiency, and improved fat and lean carcass composition effects of the growth hormones, and the discovery of genetic bases for disease resistance. Genes stimulating growth hormone production are the most likely possibility for the first commercial transgenic farm animals, especially in swine where the benefits from long term somatotropin injections is so dramatic. The recent court ruling that novel transgenic animals can be patented reduces uncertainty about whether innovators will be able to capture a share of the gains from transgenic animal research and development. However, interesting questions remain about pricing methods and royalty payments for industries new to such procedures.

Transgenic plant and microbial product introductions are likely to be much more frequent in the last five years of the next decade. Plants now undergoing field testing involve <u>single</u> gene transfers for herbicide tolerance, insect resistance, and viral resistance, or <u>single</u> gene deletion for the ice-minus bacteria. Bioinsecticides are now based on the Bt toxin. Both plant and microbial products are likely to involve combinations of genes (or toxins) for a much broader array of effects. Multiple gene transfers will be needed to achieve: desired significant change in leaf design for more effective photosynthetic activity and moisture retention capability; tolerance of moisture and temperature stress; improved standability; and increased yield in major agronomic crops. These more complicated targets for biotech research may begin to be realized in the late 1990s in some large volume grain and oilseed crops.

Value-added food products using genetic engineering, cell culture, fermentation and enzyme technology could become much more prevalent in processing and the consumer market in the late 1990s. Industrial or pharmaceutical products could be produced using agricultural crops or farm animals as the factory (e.g., drugs produced in tobacco or milk). The fragrances, flavors, and colors produced with transgenic plants or microbes should be noteworthy. But, bigger steps will be involved in manipulating oil yields and the fatty acid composition of soybeans, the protein levels and amino acid composition of major grains, and the starch composition in products like corn and rice. Consider, for example, the suggestion of one expert: Incorporating a gene for the omega-3 fatty acid from fish (considered desirable for persons with high cholesterol) into a major oilseed like the soybean, sunflower, or rapeseed. The nutritional, taste, textural, and shelf-life characteristics of major food products could be affected in significant ways in the late 1990s, though the regulatory and biological time lags for transgenic plants and, especially, animals probably will delay their major economic impacts until the 21st century.

IMPLICATIONS FOR AGRIBUSINESS

Currently, the most noteworthy biotechnology innovations likely to be marketed in the next decade are in plant and animal production. Their impact will be felt more intensely and sooner by agricultural producers and agricultural input suppliers, though a few developments will impact processors and merchandisers significantly. If technological change in agriculture in areas other than biotechnology continues at or near its recent pace, the incremental effects of biotechnology probably will accelerate the rate of technological change. These developments will place increased demands on managers in keeping informed about new developments, and capitalizing on, or coping with, the implications of these new technologies. Effective strategic planning will become more important and more difficult due to unanticipated direct or indirect effects on agricultural producers and agriculturally related industries.

Agricultural biotechnology innovations lead to: 1) production expansion, 2) cost reduction, 3) risk reduction, 4) product quality improvement, or 5) new product development. Most developments will involve more than one of these effects. For example, porcine somatotropin may reduce costs, improve product quality, and increase lean meat production per pig. Impacts that lead to increased production, improved profitability, or reduced risk will shift the individual and industry supply curves to the right, while enhanced product quality or new products for consumer or industrial markets will shift their respective demand curves, and the associated derived demand curve at the farm level. Demand curves for related products (substitutes or complements) may shift as well in domestic and international markets.

Early adopters will enjoy better profits from yield increases or cost reductions, or less risk in the short run. Their individual positive supply response to an improved situation will shift the industry supply curve, reducing prices. Nonadopters of the technology will be immediately adversely affected. If they leave the industry the adopters' aggregate supply response and price impact would be partially mitigated. But, the temporary profit surge enjoyed by the adopters will be dissipated in the long run through the industry supply response, leaving the long run equilibrium profit level unchanged. Consumers, however, may benefit by getting more and paying less, especially in markets with inelastic demand for food.

The effects of a product quality improvement or a new product are somewhat more difficult to predict. Theoretically, again, early adopters will be short-term winners. However, in the real world so much depends on how the new development is commercialized and accepted by the public.

Consumers' attitudes are crucial, for without consumer acceptance of the new or changed biotech product, it won't sell and the new technology won't be adopted. Promotional costs may be high for initial consumer product offerings from biotechnology, especially if there has been any adverse publicity about the development. Thus, general public attitudes toward biotechnology and its associated risks in food products, the work place, and the environment are important determinants of the costs involved in product development, getting regulatory approval, the actual use of the biotechnology, and the merchandising of the resulting agricultural products.

Agricultural producers

As with all new technologies in competitive industries, the first adopters would be expected to get a share of the initial benefits. New technologies offered by a biotech company should be priced attractively enough to provide economic incentive to farmers so that a relatively high market penetration rate is stimulated. The potential revenue, a combination of the volume sold and the unit price, must be sufficiently attractive economically for the biotechnology company to develop and market the product.

While biotechnology products tend not to be as capital intensive as, say, mechanical innovations, some products may require changes in operating practices. Some of the more sophisticated farm managers are more likely to be early adopters. Because they would also tend to be the larger farm operations, the trend toward larger farm size could be accelerated. At least for some biotech developments, it will be the larger farms which will enjoy more of the benefits of early adoption.

Targeted biological pest controls or growth promotants in plant production may soon be substituted for some agricultural chemicals. These could be more environmentally friendly and may offer reduced health risk for farm workers.

Genetic engineering of plants for herbicide resistance may lead to seed and chemical technology package deals and thus a link between two formerly distinct input markets. Future biotechnology developments may lead to each seed variety having strains resistant to a particular broad spectrum herbicide. In this sense the products will become more differentiated even as the market becomes more integrated, potentially providing a significant competitive advantage to both the companies producing the differentiated seed and the related herbicide.

As improved consumer or processing product characteristics are developed with biotechnology, the developers may elect to license that technology to many merchandisers or they may internalize the merchandising in hopes of capturing increased profits. This may mandate increased control of the production process by merchandisers; vertical integration or contract production may become more prevalent. If a new product is clearly better, and contract production is the only way to stay in business, some independent farmers and ranchers may have to switch rather than fight a losing competitive battle.

A few new products from biotechnology may change the climatic or stress tolerance of a crop or its susceptibility to insects or diseases found in certain areas. These developments could shift the regional comparative advantage for the affected crops. As production shifts regionally and the local crop mix changes, direct and indirect losses occur, while opportunities are created elsewhere. For example, a specialized processing facility may become remote from its raw product source.

Increased feed efficiency in the livestock sector due to biotech advances may depress demand for feed grains and, to a lesser extent, oilseed meals if overall demand for animal products doesn't increase significantly. If crop yield increases also continue, or accelerate, feed grain prices could decline. Similar productivity improvements also may occur in other crops, which may not be matched by equivalent market expansion. Since the biotechnology innovations reaching the market in the next decade appear more likely to expand supply than increase demand in the next decade, this could lead to relatively less demand for resources like land to be devoted to agriculture, and prices could be under downward pressure if some agricultural land has to shift to new, second-best uses.

Input supply industry

There are two important trends within the biotech industry; both imply greater concentration. The first relates to "biotech boutiques" begun by entrepreneurs a decade or more ago that have been unable to generate an adequate cash flow. Some of these firms unable to float new capital offerings have developed contract research linkages with other larger food product or agricultural chemical, seed, or pharmaceutical companies to fund their undercapitalized primary research activities. Others have been acquired by larger companies as an investment vehicle, or as a way to have an in-house biotechnology research group.

A second trend involves other contractual linkages or joint efforts between biotechnology firms and types of input marketing companies with well developed distribution systems to farmers. Since research entrepreneurs may lack the expertise and capital required to develop regional or national marketing systems, their linking with other firms in joint development-marketing schemes allows them to exploit economies of scale and previously sunk costs in a successful marketing operation. Also, companies strong in biotechnology research use mergers or acquisitions as a way to capture more fully the economic benefits from their research. The seed industry has seen significant acquisition activity over the last several years, as some investors attempt to capture more of the benefits from recombinant germ plasm for the large-volume commercial crops. Thus, a number of biotechnology ventures have lost some or all of their independence, as contractual or ownership vertical integration links are being forged in the agricultural input supply industry.

Both genetic engineering of plants for insect and virus resistance and biological controls for plant pests appear likely to reduce use of some chemicals. Herbicide resistance engineered into plants may displace the use of certain chemicals and may also displace labor in some labor-intensive crops like tomatoes. As input displacements may occur, input suppliers may find themselves facing an unanticipated competitor.

The product lines of farm input supply companies will undoubtedly expand: new diagnostic tools like monoclonal antibodies, new vaccines and immunity system enhancers; differentiated seeds engineered for particular herbicides, pests, or viruses, or other product or yield characteristics; and new animal growth promotants.

If commercial farm animal productivity is significantly improved, with less feed required per unit of consumer product, the feed industry could be in line for a significant adjustment. More sophisticated ration management by larger operators, with a different mix of feed stuffs and services required for potentially fewer animals in some species--all this may lead to significant adjustments in the industry.

More complex technology requires more sophisticated management, which may lead to larger farms. As these farms deal with their input marketing firms, more direct marketing with an increasingly sophisticated sales force may be required by the feed, seed, animal health, and related industries serving farmers and ranchers.

<u>Food processing and merchandising</u>

The short-term effects of biotechnology appear to be improved efficiency in food processing enzyme and fermentation technology. Greater use of fermentation or cell cultures for production of relatively high cost colors or flavors may occur relatively soon, but significant changes in other food product characteristics (and corresponding product differentiation in food processing and merchandising) due to biotechnology will occur more slowly. The first impact will be efficiency gains and cost advantages for some food processors. Later will come more noticeable changes in consumer product characteristics. Changes at the processing level could have significant impact on procurement methods for raw materials (more contract production and vertical integration) to maintain control. In addition, more highly differentiated products may involve increased segregation in the handling and distribution systems, more sophisticated grading and quality control systems (especially where product differences aren't visually apparent), and more branded products supported by advertising and promotion.

As we have noted, consumer acceptance could be a significant problem in these early stages of biotechnology. Public concerns about BST have certainly prompted a significant corporate education effort long before it is actually marketed. Similar steps may be necessary in other areas as new products are developed.

Conclusion

The biotechnological revolution is in its very early stages. It promises much, but, as with any revolution it will bring about many changes. While the pace of change will be slow initially, which may ease the adjustment process to some extent, the pace of change will quicken. While there will be significant benefits, some adjustments will be required that clearly will have costs attached for some agribusiness firms.

Differing national regulatory environments around the world will affect where and how fast the products of biotechnology will appear. Just as the early adopters gain individually, so may the early-adopting nation. Regulatory differences between nations could determine who wins and who loses internationally in the new dynamic environment of the biotechnology revolution.

For effective strategic planning, agribusiness firms need to develop an early warning system for those biotechnology innovations here and abroad which may provide significant opportunities or problems. Otherwise, opportunities will be seized by competitors, and adverse shocks may not be absorbed or countered effectively.

University research and extension programs can help ease the inevitable transition by educating the public and the agribusiness sector regarding biotechnology, its promise and problems, and providing an early warning system on forthcoming innovations and their implications.

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